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SHIP WAKE STUDY USING IMAGING TECHNIQUE

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ABSTRACT

Stimulated by the importance of reducing pollution caused by ship wakes, this study is conducted to design a better hull model that can produce less wave resistance. It is very crucial to measure the ship wake produced during the design stage. The system implemented is based on stereophotogrammetry principles. By using stereophotogrammetry system, the floater motion that represents the ship wake can be obtained in XYZ-coordinate. Five major stages in design and development of the system are stereo-camera calibration, design and development of stereo-camera platform, design and development of system control frame, data capture and finally data processing stage. Two experiments are conducted to validate the system. Firstly, system calibration in static water condition and another one in wave condition. The result is compared with the control result. After improvements and validation, the system is used to measure the ship wake using test model, MTL038 26m stern trawler at the speed of 5 knots. From the result, it shows that the system can successfully measure the ship wake produced from the model test.

Keywords: ship wake, imaging, close-range photogrammetry, 3D modeling

1.0 INTRODUCTION

Recently, ship wake has caught the attention of authorities and environmental agencies. Most of the ship operators and ship builders are interested in "low wash" design ship, especially in the case of ferries and coastal vessels. In addition, the number of institutions and organizations who's conducting a research within this field is growing rapidly. However, the method of obtaining and reporting the wave height generated by a vessel is different throughout the industry. The restrictions and concern about the ship wake has added a new parameter to be considered by the ship designer, builder, operator and owner of the vessel. Therefore, the size of the wake wash created by a passing vessel need to be investigated in the design stage before it is used in operation. This is normally done during model testing stage using wake measurement technique.

There are various methods to measure ship wake wash can be categorized into contact and non-contact method. Examples of contact methods are wave probes and ultrasonic wave measurement in cylinders while examples for non-contact method are Synthetic Aperture Radar, satellite, laser and photogrammetry technique. This paper presents a method based on close-range stereophotogrammetry to capture and measure wake surfaces.

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2.0 METHODOLOGY

2.1 Selection of the most suitable method

The ship wake must be analyzed using certain method. In an effort to quantify the ship wake, Macfarlane and Renilson (1999) provided a guideline for those who want to study about ship wake.

According to Macfarlane and Renilson (1999) , before any useful regulation or criteria is developed and implemented, an acceptable base measurement must be established. It will be easier to generate a method or conduct an experiment using a standard guideline. The basic idea of this project is to distinguish ship wake that produced from different vessel. By focusing on the numerical measure, comparison can be done. There are six numerical measures for the suggested method to meet given in the **Table 1** below:

Table 1. Requirements of a standard measure

Type	Standard Numerical Measure
1	Independent of length of data sample
2	Able to be used to compare one vessel against another vessel
3	Easy to understand
4	Representative of the wave wake problem
5	Independent of exact distance from vessel sailing line
6	Easy to measure

Some additional criteria are proposed such as:

- The number of variables must be limited if the criteria are to be applied without resorting to individual vessel testing;
- The criteria and their variable inputs should not be over-simplified to the point where their effectiveness is diluted;
- The degree of subjectivity in deriving the value of the variables must be reduced, otherwise the criteria will be open to manipulation and abuse; and,
- Any empirical equations derived must have a proper mathematical basis and obey the laws of similitude (i.e., must have certain properties that retain their mathematical integrity with varying input data so as not to be specific only to the data from which they were derived)

Based on the literature review, there are several imaging methods found and after several considerations one of the techniques to be used in this study is chosen. The techniques are as follow:

- Reflected light distribution method
- Grid projection method
- Close range photogrammetry
- Wave particle velocimetry
- Optical triangulation method

Based on the literature review, all the prediction methods are analyzed by making comparison between them. The criteria considered are stated in **Table 1**. After conducted an analysis, the method that will be used is close-range photogrammetry. The selection of this method is because the expertise and the equipment are available and the flexibility of experiment setup, it can be use by attaching the setup to towing carriage.

2.2 Stereocamera Geometric calibration

The main part of the system is two off-the-shelf DSLR cameras. The camera used is Sony Cybershot DSC-F828, with 7.1mm focal length. The cameras are calibrated independently because each camera has different properties although they are the same model. Prior to use the stereo camera must be calibrated. In this study the laboratory calibration method is used because the method is more convenient, accurate and generally used to calibrate imaging devices. Geometric calibration purpose is to determine the calibration parameters or constants. These constants are referred as element of the interior orientation needed in order to accurately extract the spatial information from the photographs. The constants are:

- ***Calibrated focal length, f***: A focal length that produces overall means distribution of lens distortion. It represents the distance from rear nodal point of the lens to the principal point of the photograph. Manufacturer usually states the focal length of the camera but the value changed after several uses. Hence, to make sure the exact focal length value, calibration process is extremely important.

- ***Symmetric radial lens distortion, k1, k2 and k3***: A symmetric component of distortion that happen along radial lines from the principal point. The values usually very small and can be ignored however they must be considered to obtain accurate data from image processing.

- ***Decentering lens distortion, P1 P2***: Lens distortion that remains following compensation for symmetric radial lens distortion. These distortions are caused by the defect during manufacturing and misalignment of the camera lens.

- ***Principal point location, Xp Yp***: This is specified by principal point coordinates given with respect to x and y coordinates of the fiducial marks. The principal point location is in x and y coordinates.

These four parameters can be obtained by calibration process and the calibration of the camera has been done at the first stage of the study. The stereo cameras are calibrated separately as the camera may have different focal length and length distortion values. The calibration process is carried out by using camera calibration test field. Australis software is used to measure the calibration parameters.

2.3 Stereo camera platform

To obtain the depth or z-axis coordinate, stereo photogrammetry is used and the requirement is that both stereo cameras have overlap area more than sixty percent. This ratio is used to determine the distance between stereo cameras in order to achieve sixty percent overlap area when the distance of the object from the camera is known. The stereo camera platform is the platform used to attach the camera so that the stereo camera is fixed at one position. The design and development of stereo camera platform is based on the stereo photogrammetric concept on base to height ratio. The base is the distance between two cameras and the height is the distance between stereo camera and the object which is the water surface. The platform for the stereo camera is designed to be adjustable so that the area of interest can be observed.

The height, H` or the distance of the stereo camera from the object is set to 600mm. The format dimension, d is stated by the stereo camera manufacturer. PE is the coverage area. The value is set to 60. After all the parameters are known, the distance between stereo cameras can be calculated.

To obtain z-axis coordinate, stereo photogrammetry is used and the requirement is that both stereo camera have an overlaps area not less than sixty percent. This ratio is used to determine the distance between stereo camera in order to achieve sixty percent overlaps area when the distance of the object from the camera is known. **Figure 1** below show the theory of base-height ratio.

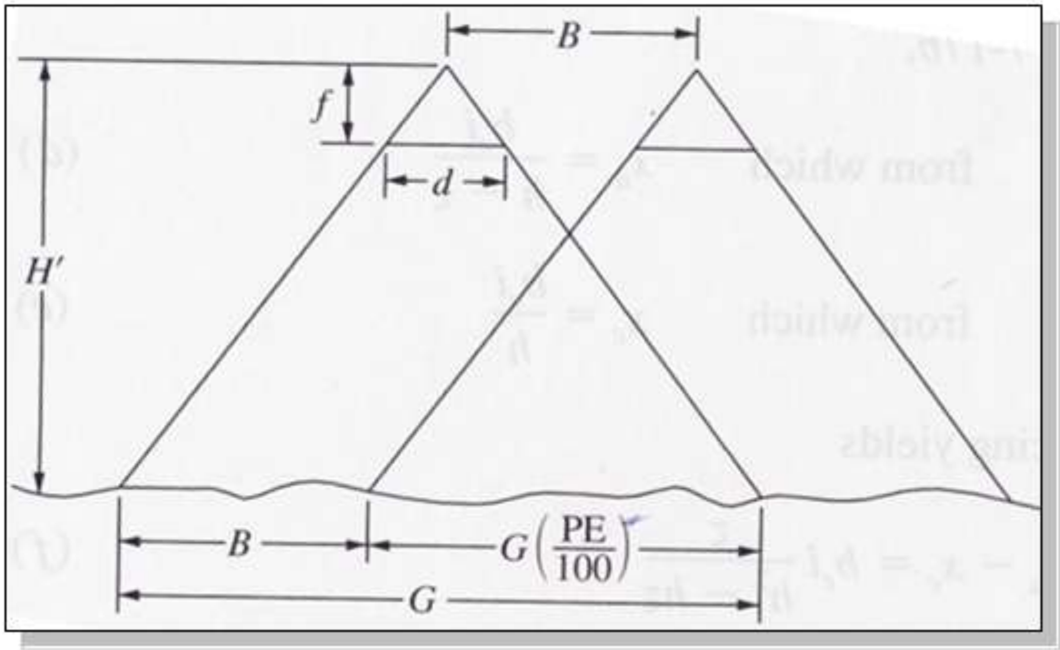

Figure 1. Base-height ratio principles

In **Figure 1**, G represents the total coverage of a vertical photo taken from vertical altitude H` from bottom. Air base B is the distance between stereo cameras. From **Figure 1**,

$$B = G - G\ \frac{PE}{100} = G\ (1 - \frac{PE}{100}) \tag{1}$$

Where PE is the required percentage of overlap, must be sixty percent to hundred percent. From **Figure 1** also

$$\frac{H`}{G} = \frac{f}{d} \tag{2}$$

Where f is the focal length and d is the format dimension

Divide equation 4.3.1 and 4.3.2 give

$$\frac{B}{H`} = \left(1 - \frac{PE}{100}\right)\frac{d}{f} \tag{3}$$

2.4 Design and the development of control frame

The next part is to design and construct a photogrammetric control frame. The function of the control frame is to provide 3D coordinates on the area of interest that will be measured on the water surface. The control frame function in stereo photogrammetry is to provide controlled or known XYZ coordinate to the photograph. Hence, during data capturing process the control frame and the area of the study must be visible and clear in the photograph. The size of control frame is determined by the area of the study. The control frame consists of retro-reflective target that located on a plate or bar that have differences in elevation. In this study, the area of interest is 400mm length x 350mm wide. The control frame is designed using thin steel plate and thirteen retro-reflective targets are placed on the steel plate. Following recommendations by Chong (2010), the height of elevation point design on the control frame is kept at ten percent of the height from the control frame to the stereo camera focal point.

2.5 Data capture

The data capture process was done manually. Both cameras were connected with a synchronizer to ensure both camera captures exactly in the same time. During data capture, many aspects have to be considered such as the lighting condition, external disturbance, safety of equipments and to make other parameter constant in order to get the best photograph for the next part of the process. The external lightning and the position of the stereo camera during data capture was adjusted by trial and error method. Flash was not used as recommended by Shortis (1996). It is also essential to get plenty of images to make sure that there will be no repetition of data capturing process.

2.6 Data processing

The data processing task involved the stereo photogrammetric processing which includes the exterior, relative and absolute orientations process to generate the stereo model of the ship wake. The image processing software used is Australis 6.06. The software provides a complete package of image processing from stereo camera calibration to image processing capabilities. It also provides automated off-line measurement and high precision measurement. The measurement of the ship wake involved stereo-digitizing points of interest on the water surface. The final output from the measurement is a set of 3D coordinates of the relevant points on the water surface. The complete system is shown in **Figure 2**.

Figure 2. The complete ship wake imaging system

2.7 System Calibration

The system calibration is carried out by capturing and measuring a known wave profile. The measurement was carried out in the 120m towing tank of Marine Technology using a wave profile of Hw = 0.058; Lw = 2.88m; Tw = 1.36. The water in the towing tank is clear and hence it was difficult to capture the water surface. Therefore fishing line floaters were spread on the water surface. The system measures the centre position of the floaters to get the z-axis coordinates of the water surface. Simultaneous data recording was carried out using wave probe and the camera system. The schematic of this experiment is shown in **Figure 3**.

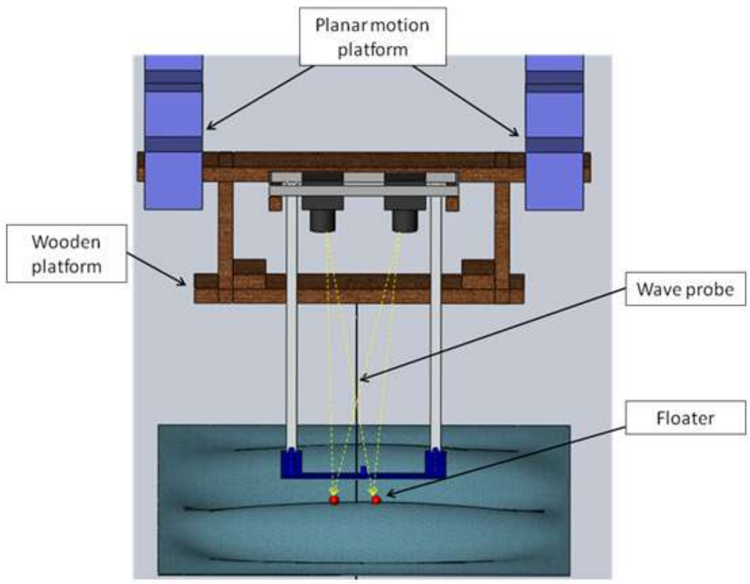

Figure 3. The system calibration in wave condition

2.8 Ship Wake Experiment

A 2.6m long ship model was towed in the towing tank and the system was used to record the wake produced as shown in **Figure 4**. Floaters were released in front of the moving ship model and the movement of the floaters were captured using video mode. Three sets of experiments were conducted using video mode of stereo camera. This is done to measure and analyse the model ship wake at different position starboard of model. The study area position from Y/LWL= 0.17 to Y/LWL = 0.26 from the centreline and X/LWL= 0.30 to X/LWL 0.57 from the FP of the model. The Froude depth number is 0.164.

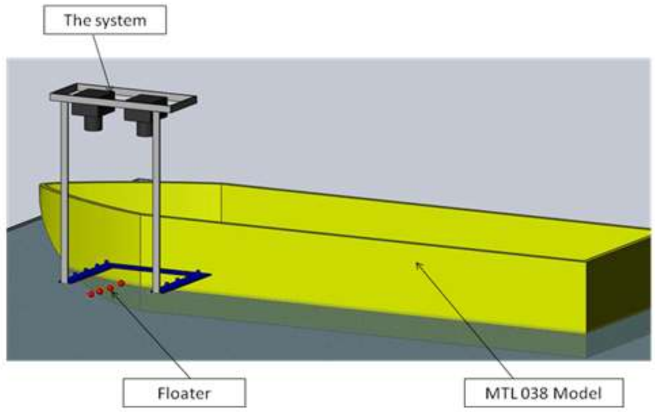

Figure 4. Schematic of ship wake experiment setup

3.0 RESULTS AND DISCUSSIONS

3.1 Calibration of the system in wave condition using video mode

Two sets of experiments were conducted and the result is shown in graph form. The first experiments used the manual capturing method while the second used the video mode capturing method. The analysis of the data was done using the statistical tool, root-mean-square (RMS) deviation. RMS is used because comparison can be done with the control data from wave probe. This function used to compare the result of wave height from wave probe with the data obtained from the system.

Figure 5 shows that all system data tabulated within the maximum and minimum value of wave probe except at time = 40 s. The mean of the system is shifted slightly below the mean waterline given by the wave probe. This is due to the error from manual data capture and image processing. The error that greatly effected the result of this experiment is the stereo camera limitation in image capturing that is only 0.2 Hz compared to the wave probe data acquisition that is 25 Hz. Manual acquisition means the acquisition rate is not exactly constant while other errors are caused by difficulty in image processing because of some blurry images.

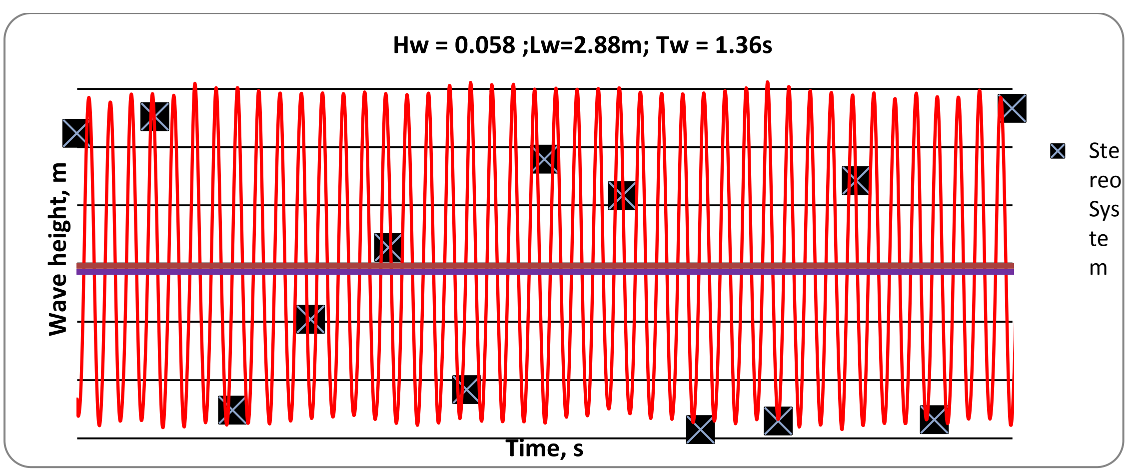

Figure 5. Graph of wave profile Hw = 0.058;Lw = 2.88m; Tw = 1.36s

Figure 6 shows the graph of comparison between stereo-camera system data and wave probe data by using video capturing method. Wave profile of Hw = 0.058; Lw = 2.88m; Tw = 1.36. By using video mode, the system shows greater ability to obtain images which is at the rate of 25 Hz. Video mode also made it possible to obtain the wave profile.

The limitation seen in manual still capture was overcome by using video capturing mode during the experiment. By using this mode, it enables high capturing frequency that is 25 Hz and sufficient data can be obtained to plot the wave profile graph. However, during stereo camera calibration; processing the image and low image quality compared with still images has contributed to error. The system accuracy is second highest that is ±4.174mm.

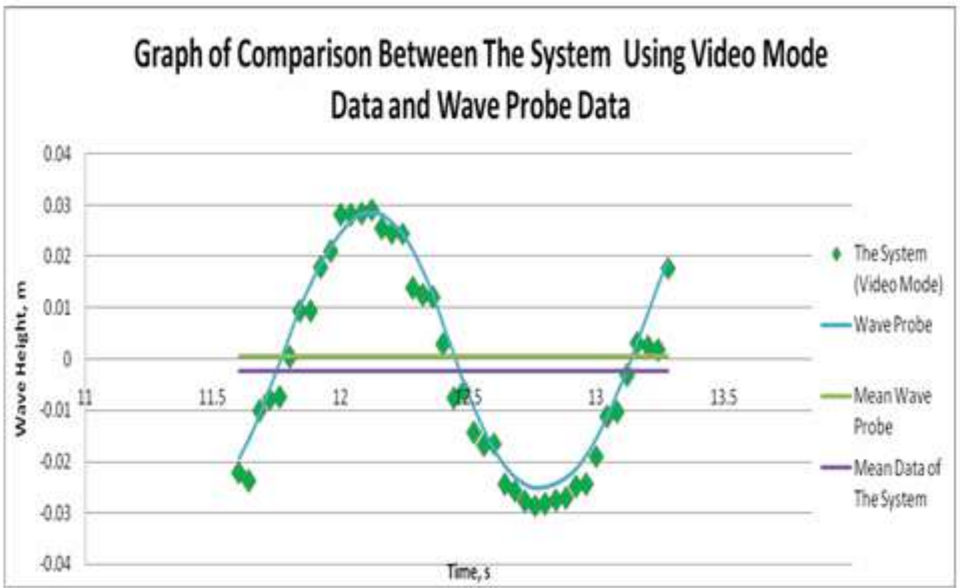

Figure 6. Graph of comparison between the system using video mode data and wave probe data

3.2 Ship wake experiment using model results and discussions

A total of four sets of analysis were obtained from this experiment that is at Station 8, between Station 7 and 6, at Station 5 and from Station 8 to Station 5.

3.2.1 Result at Station 8

This is the most forward region of ship wake study from other two locations. From the total of 39 points (in XYZ-coordinate) on the surface, a model of a ship wake is plotted. The maximum wake height 0.014 m occurs at the location (0.296, 0.248) X/LWL and Y/LWL. **Figure 7** shows the ship wake analysis.

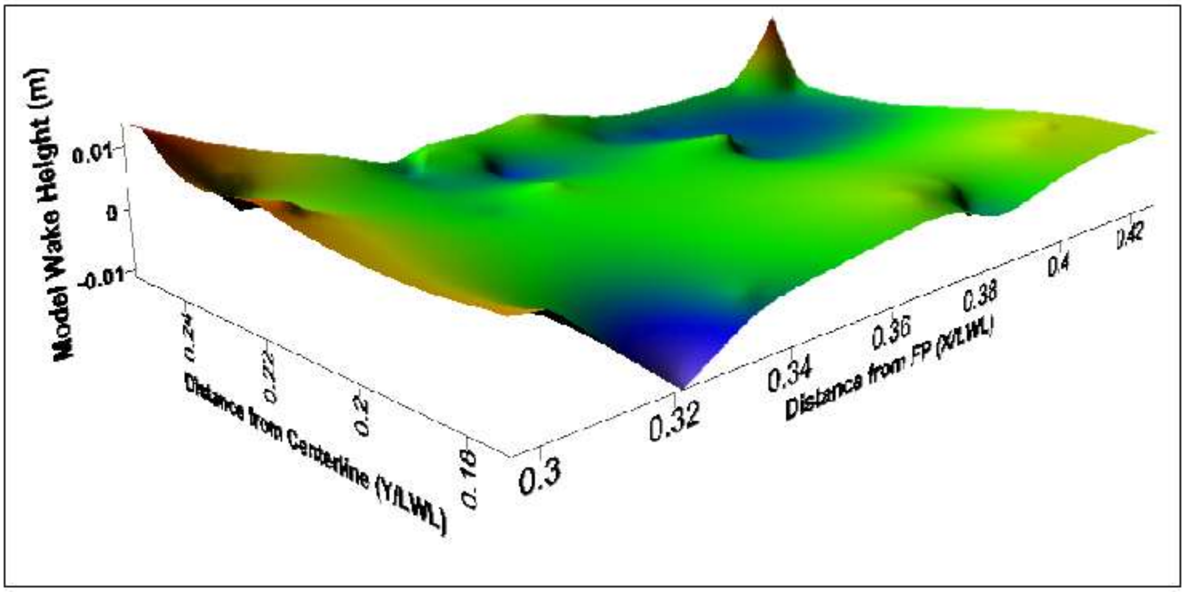

Figure 7. Surface of ship wake height at Station 8

3.2.2 Results between Station 7 and Station 6

This is the middle region of ship wake study from other two locations. By using 36 points (in XYZ-coordinate) on the surface, a model of a ship wake is plotted. The maximum wake height is 0.00938m occurs at the location (0.393, 0.196) X/LWL and Y/LWL. **Figure 8** shows the ship wake analysis obtained.

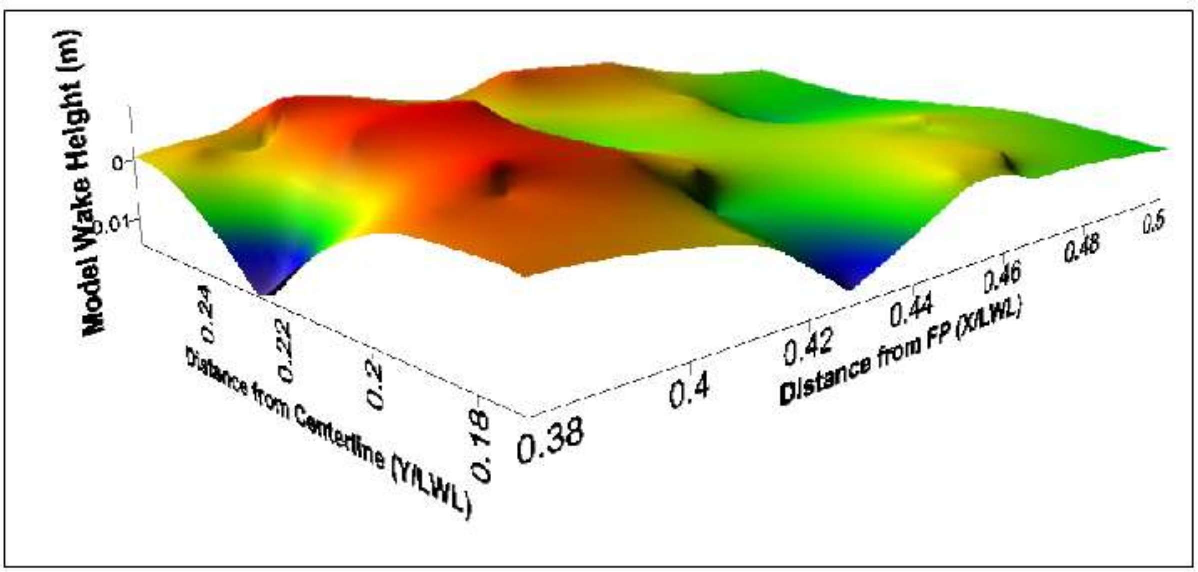

Figure 8. Surface of ship wake at between Station7 and Station 6

3.2.3 Result at Station 5

This is the last region of the ship wake study from other two locations. From 38 points (in XYZ-coordinate) on the surface, a model of a ship wake is plotted. The maximum wake height is 0.00739 m occurs at the location (0.474, 0.202) X/LWL and Y/LWL. **Figure 9** shows the ship wake analysis obtained.

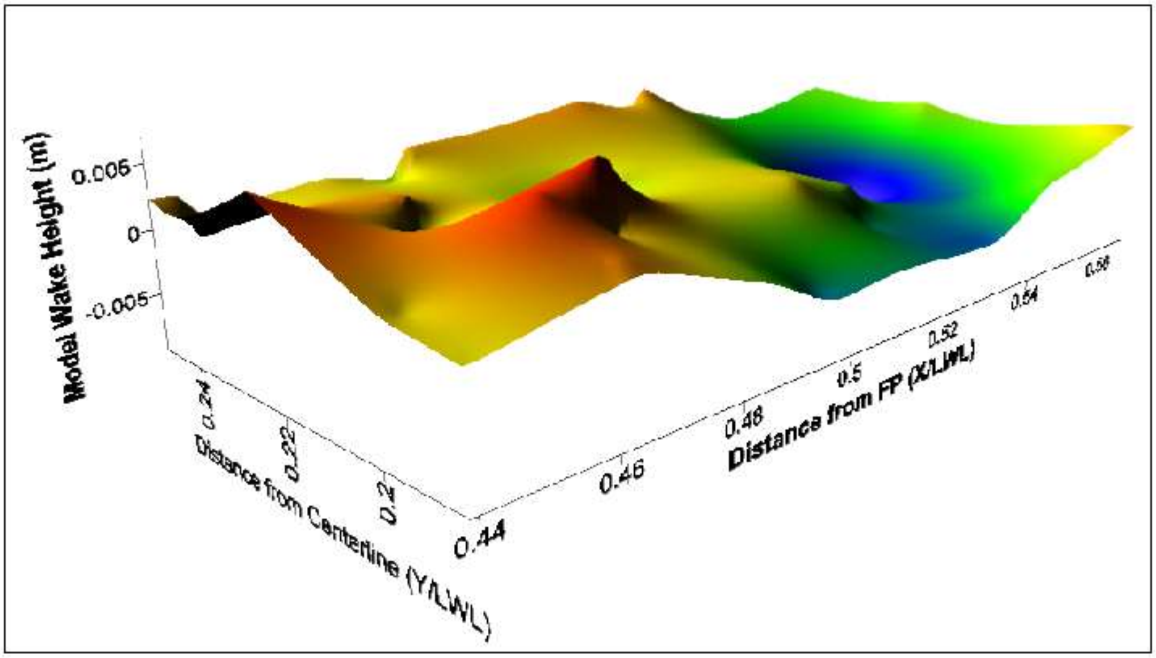

Figure 9. Surface of ship wake at St 5

3.2.4 Result from Station 8 to Station 5

By combining all three regions that have been analyzed, **Figure 10** represents the overall ship wake surface from Station 8 to Station 5. The maximum wake height recorded is 0.0140 m at the location (0.296, 0.733) X/LWL and Y/LWL respectively. From the result, the system had shown that it is capable to measure model ship wake.

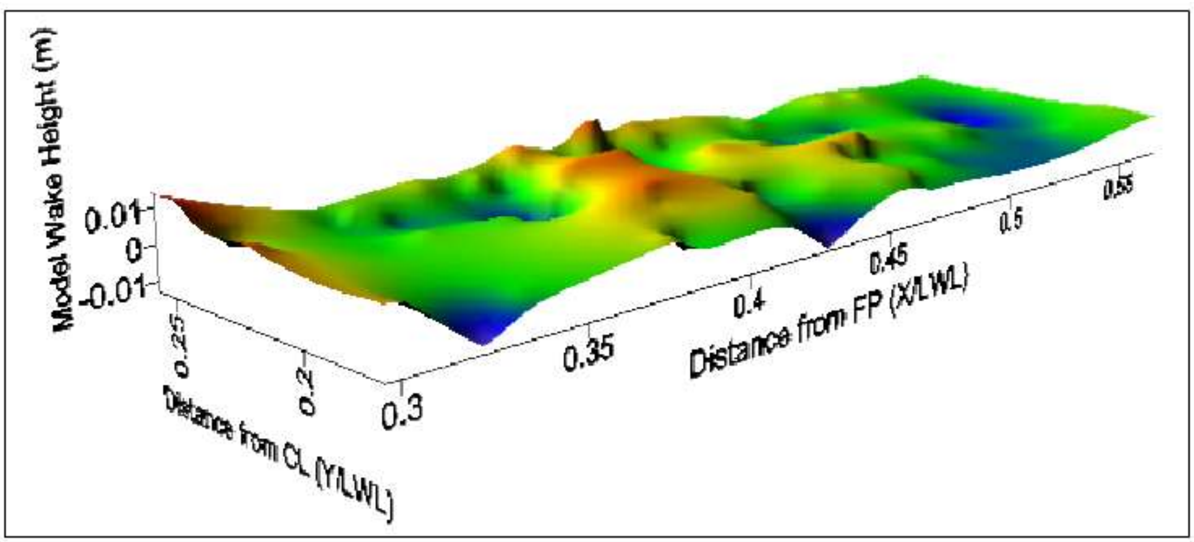

Figure 10. Surface of ship wake from Station 8 to Station 5

3.3 Overall discussion

All the data collected using manual data capture cannot be plotted continuously in the graph to obtain the wave and ship wake profile because of capturing capability. To obtain actual profile of the wave and ship wake, the system must be able to capture at least ten times higher than the highest signal. This means that if the shortest estimated period or control period is t second, then the image must be captured at time interval of t/10. This is using the Shannon`s sampling theorem. To eliminate this error, the second experiment is conducted using video mode with capturing frequency of 25 Hz.

The video mode improved the data capturing ability. Using the system with video mode to measure the wave generated by the wave generator and then compared the result with the wave probe; it showed that the system accuracy in measuring wave is ±4.174mm. The system is successfully calibrated and it is used to measure ship wake model in the towing tank. The system is used to obtain XYZ coordinate of the floaters that runs freely and from the coordinates, the surface of the ship wake is plotted using Surfer software.

4.0 CONCLUSIONS AND RECOMMENDATIONS

This study has successfully explained and showed the important parameters and considerations to design and develop close range photogrammetric system which is able to obtain and analyse the wave and wake profile. The system design and development has successfully completed using the theory and requirement of close range photogrammetry. It can obtain wave profile during system calibration in wave condition with accuracy of ±4.174mm using video capturing mode. In addition, it is also obtained the ship wake profile of 26m Stern Trawler (MTL038) from Station 8 to Station 5. All the design, development and result in this study can be used to improve and acquire the characteristic of ship wake.. Some recommendations to improve this study are:

- ***Improve the system so it can be used to measure larger wake area***

  The current system can only study 0.3m x 0.3m (length x wide) area of ship wake. Improvement can be done if the study area is larger ship wake area.

- ***Use the system to determine low wake hull design***

  The wake generated from the ship model can be analyzed using current system. By conducting experiments using different types of model, the parameters that contribute to ship wake can be determined. Further study is possible for determining low wake wash hull design.

- ***Used high definition video camera as stereo camera***

  The current system only used DSLR camera to capture the motion of the floater. By upgrade the system using high definition camera, the result should be more reliable.

- ***Develop algorithm that can process a large amount of photograph or video format data automatically to reduce the processing time.***

  Using Australis software to analyzed the photograph demand a large amount of time. By using programming to develop algorithm or software that can analyzed a large amount of photograph or video format data greatly reduce the processing time.

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